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Experimental and Numerical Modelling of Stratified Exchange Flows and Blocking over a Submerged Sill

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ABSTRACT

Results are presented showing direct comparisons between physical laboratory experiments and lab-scale numerical simulations using the Bergen Ocean Model (BOM), a three-dimensional general ocean circulation model (https://org.uib.no/bom), of stratified exchange flow and saline intrusion blockage across an idealized, submerged sill. The experiments were conducted in a large rectangular channel with a trapezoidal sill incorporated to control exchange flow between adjacent saline and fresh water basins (Cuthbertson et al., 2018). The sill submergence depth, density difference between fresh and saline waters, and relative magnitude of inflow volume fluxes into each basin were varied systematically in the simulations. High resolution particle image velocimetry and micro-conductivity probes were used to measure velocity fields and density profiles generated across the sill under different parametric conditions. Experimental and numerical results indicate that saline water intrusion across the sill, as part of a well-defined, two-layer, stratified exchange flow, can be blocked under specific parametric conditions that depend on the relative magnitude of the fresh and saline water inflows and the sill submergence depth. BOM simulations are now being extended to consider the influence of rotation (i.e. Coriolis effects) on the exchange flow dynamics and saline blockage mechanisms.

1. Introduction

Restricted, density-driven, exchange flows occur in oceans, seas and coastal margins when adjacent water bodies with different densities are connected by narrow channels or straits (e.g. Gibraltar, Bosphorus, Baltic Sea), or where natural topographic obstructions such as submerged sills control the intrusion of saline water into fjordic basins (e.g. Norway, Scotland). It is thus important to study both idealised laboratory scale models and complementary numerical simulations to gain a full understanding of the parametric controls on these stratified exchange flows, and the conditions under which these flows can be blocked, for scenarios where the Earth's rotation either influences or has no effect on exchange flow dynamics.

Figure 1 shows a schematic representation of the problem under investigation. The channel/sill dimensions and imposed or measured parameters for the stratified exchange flow across sill *S* are given. Note: subscripts 1 and 2 refer to fresh and saline water, while *M* and *I* are the "marine" and "impoundment" basins, respectively.

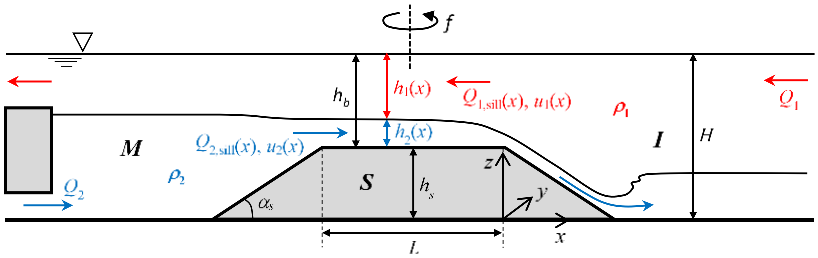

Fig. 1. (a) Schematic representation of physical system under investigation

In all experimental (and numerical BOM) simulations, the saline water inflow flux Q_2 was held constant while the fresh water inflow Q_1 was increased incrementally in steps throughout the runs. The inflow flux ratio Q^* (= Q_1/Q_2) was therefore a primary control on the stratified exchange flow generated across the sill.

2. Results and Comparisons

Figure 2 shows experiment-BOM comparisons of synoptic horizontal velocity fields generated across the sill for $Q^* = 0.43$ (other parametric conditions given in caption), while Fig. 3 shows corresponding density profiles at the mid-point (x/L = -0.5) of the sill for range of Q^* values shown. Overall, the level of qualitative agreement is high, although BOM predictions typically overestimate the saline intrusion flux $Q_{2,sill}$ across the sill, relative to experimental measurements. This is indicated in Fig. 4, which plots the sill volume flux ratio Q^*_{sill} (= $Q_{1,sill}/Q_{2,sill}$) calculated at different sill positions (x/L) from velocity profile integration, where $Q^*_{sill} > Q^*$ at higher imposed Q^* boundary conditions indicates increasing restriction of saline intrusion across the sill. Differences in experimental and BOM results are attributed primarily to model representation of (i) mixing and entrainment processes between the counterflowing layers across the sill, and (ii) specification of the inflow and outflow boundary conditions within the modelled domain.

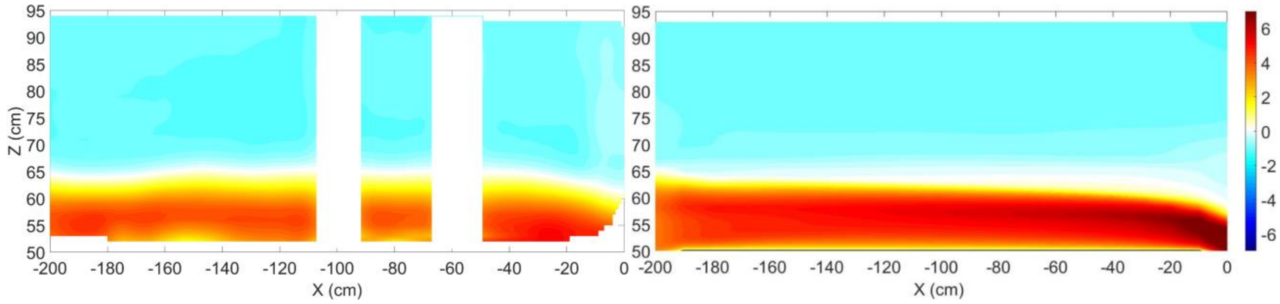

Fig. 2. Synoptic horizonal u velocity fields for stratified exchange flow across sill crest for $Q^* = 0.43$ [run with $\Delta\rho = (\rho_2 - \rho_1) = 5.1$ kg m^{-3}; h_b = 0.43 m]. Experimental measurement (left) and BOM simulation (right) shown. Colour bar represents velocity magnitude [cm s^{-1}]

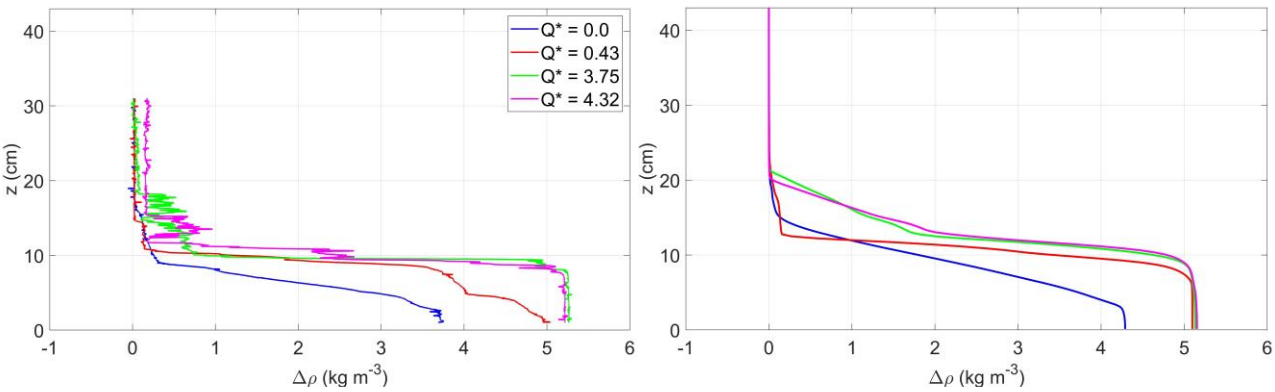

Fig. 3. Experimental (left) and BOM simulated (right) density profiles across sill at x/L = -0.5 for Q^* values shown.

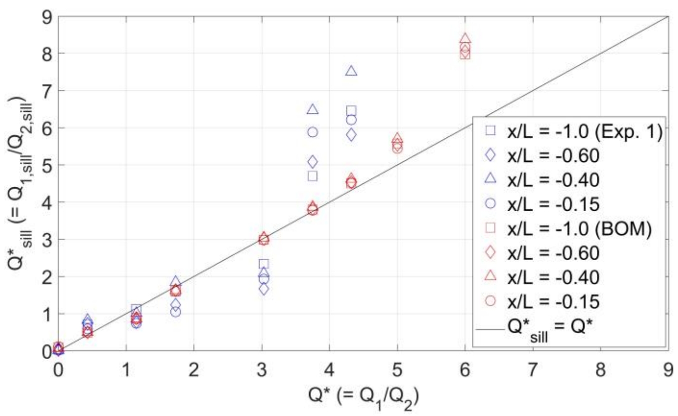

Fig. 4. Measured (blue data) and BOM simulated (red data) sill volume flux ratios Q^*_{sill} at different x/L locations versus imposed Q^*

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